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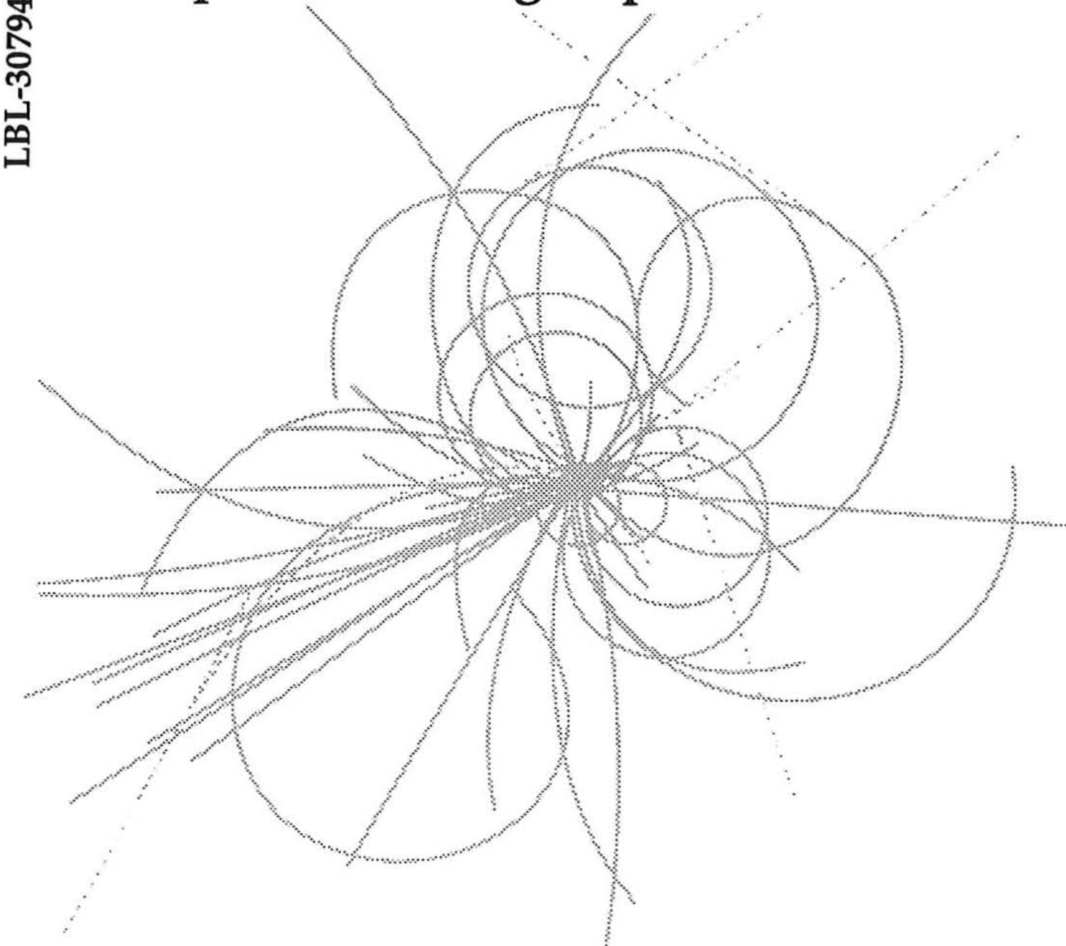
Superconducting Super Collider Laboratory



Debunching and Capture in the LEB for the SSC

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DEBUNCHING AND CAPTURE IN THE LEB FOR THE SSC

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Abstract

We present the details of the capture process in the Low Energy Booster (LEB) for the SSC. We consider only the longitudinal dynamics. Space charge forces are computed quasistatically. The beam pipe is considered to be perfectly conducting. With respect to maximizing the capture efficiency and minimizing the space charge tune spread, initial few milliseconds are very important. We present only the first few milliseconds of the cycle, during which space charge effects are significant. For the numerical simulation we use the code ESME.

1 Introduction

The Low Energy Booster (LEB) is the first of the synchrotrons of the SSC accelerator complex. This makes the LEB a critical and complex machine. The LEB has to capture several bunches coming from the LINAC, and bunch them into a single bunch, and accelerate them from $\beta = 0.7924$ to 0.9969. This gives rise to several problems in the design of the LEB. The most important problem, of course, is the significant space charge forces during the initial stage of the cycle. To understand the effect of space charge forces one has to consider the longitudinal and transverse dynamics; this is the subject of another study, preliminary results of which are presented at these proceedings[1]. Here we will, however, confine ourselves to the longitudinal dynamics and construction of the rf voltage program for the LEB. We do not wish to discuss the advantages and disadvantages of different capture procedures. We present here the adiabatic capture process;we, however, remark that the LINAC frequency has been selected such that the painting scheme could also be adopted.

In adiabatic capture in a resonant system, it is customary either to inject in advance of the momentum curve or to inject a little above the reference energy. This is done to achieve debunching of the linac bunches and to capture them while the synchronous phase is low. For example the FNAL booster injects about 100 microseconds before the bottom of the magnet ramp curve[2]. Similar results can be obtained by injecting at the bottom of the momentum curve but at some what higher energy[3]. In the rf program we propose here we do not do either. The resultant transmission and bunching factor, however, are similar to the FNAL booster. Ideas involved in the construction of the rf voltage program are explained in Section 4.

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Parameter	Nominal Value
Kinetic Energy	600 MeV
Longitudinal emittance(rms)	6×10^{-7}eV s
Energy Spread(rms)	0.105 MeV
Length(rms)	1.63 cm
Jitter(rms)	0.075 MeV
Transverse Emittance(rms)	0.4 π mm mrad

Table 1: Microbunch Characteristics

2 Injection Parameters

Although the actual particles injected are H^- ions, they are immediately stripped of the two electrons in the stripping foil. The injection into the LEB is multi-turn; here we consider four turn injection. In each turn the LINAC will inject 9 microbunches into each of the LEB bucket. The rf frequency of the LINAC will be so adjusted that the 36 microbunches in an LEB bucket will be equally spaced. The microbunches at the end of the LINAC have a large energy spread; however, after passing through a drift and a compressor the energy spread is reduced[4]. During this process the microbunch is sheared (in phase space) so that it becomes longer, thereby reducing the charge density along the bunch. In addition to the energy spread the average energy of the microbunches has a jitter. Table 1 summarizes the characteristics of the microbunches.

3 LEB Parameters

The LEB has superperiodicity of three with three long straight sections. One of the straight sections is for the rf cavities and the other two are for injection and extraction. The parameters relevant to longitudinal dynamics are

Parameter	Nominal Value
Injection Momentum	1.219 GeV/c
Extraction momentum	12 GeV/c
Harmonic Number	108
Circumference	540 m
Transition Gamma	21.26
Transverse Tune	11.8
Repetition rate	10 Hz
Maximum rf voltage	725 kV
Protons/LEB-bunch	10^{10}

Table 2: The LEB Parameters

listed in Table 2 above. These parameters have changed recently; the new parameters are given in these proceedings[5].

4 The Rf Voltage Program

As noted above, construction of the rf voltage program should minimize the space charge tune spread (a measure of which is given by Lasslet tune shift) and have an adequate transmission. Complete debunching will require a small synchronous phase angle to capture a high fraction of particles. This, in turn, requires a high rf voltage. Higher voltage, though, gives a large bucket area, does not guarantee that bunch area will be large. It is the bunch area and how tightly the bunch fills the bucket that determines a favorable bunching factor. For a given bunch area a small-height bucket (but higher than the bunch) tends to give a longer and small-height bunch. The allowable bunch area, of course, is determined by the limits on the rf voltage. This then determines the energy spread necessary for the microbunch. Thus the rf voltage must be so constructed that the bucket is quite full. Once the relativistic effect more than compensates the bunching process, however, the bucket area should be further increased to prevent the loss due to slow attrition during the acceleration cycle.

Good transmission, in addition to avoiding long term attrition, must also capture a good fraction of particles in the initial moments. We achieve this by a partial, rather than a complete, debunching of the microbunches. More details of this mechanism are given else where[6]. Here we present the resulting rf program.

Figure 1 shows the bucket area as a function of time. For the first 30 μs (about 13 turns) the voltage is kept at a minimum, preferably at zero; we have used the value of 4 kV as practicable. Then the voltage is smoothly but rapidly increased up to 0.5 ms such that a bunch fills the bucket quite tightly. The bunch area (95%) at this moment is about .03 eV s in comparison to the bucket area of 0.038 eV s. The bucket area is maintained at .038 eV s up to 3 ms, by which time the relativistic effect is able to compensate further bunching. This tight a bunch can not

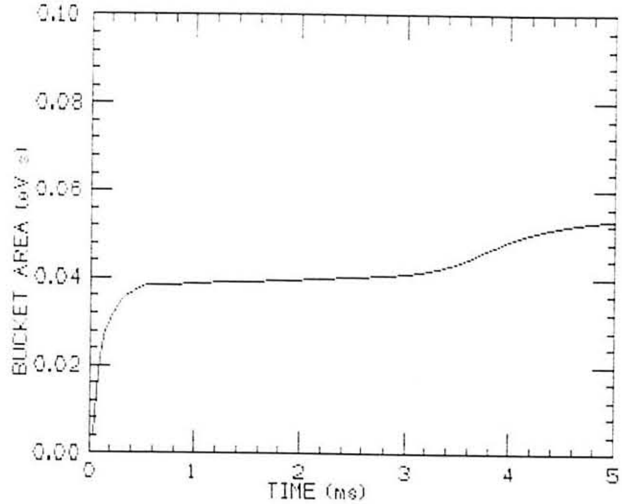

Figure 1: Bucket Area vs Time

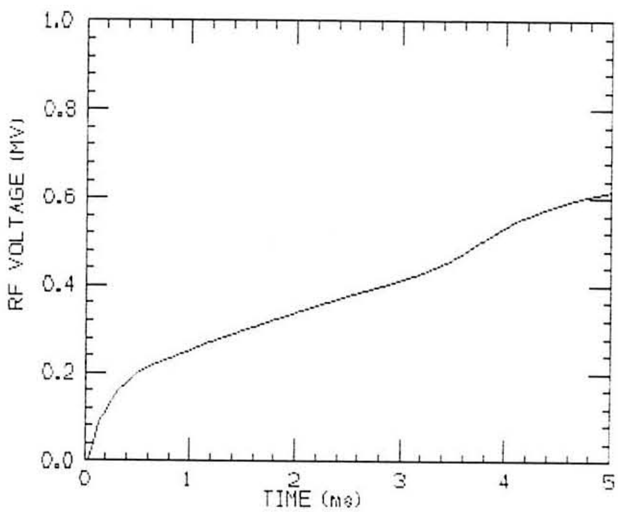

Figure 2: Rf Voltage vs Time

be maintained without further loss of particles as the synchronous phase angle is increased. Therefore the bucket area is further increased to .054 eV s between 3 to 5 ms. This bucket area is then maintained (not shown in the figure) until 30 ms, beyond which it can not be maintained due to the decrease in the value of slip factor and phase angle. Based on the above ideas the rf voltage program, the first 5 ms of which is shown in Figure 2, was constructed using the program RAMPRF presented else where in these proceedings[7].

5 Simulation and Results

We use the code ESME for the tracking simulation. 43,200 particles (1200 in each microbunch) were tracked. To account for the jitter in the energy, the energy spread and the jitter were added in quadrature. Space charge effects including the conducting wall are included in the simulation. The space charge calculations are based on a qua-

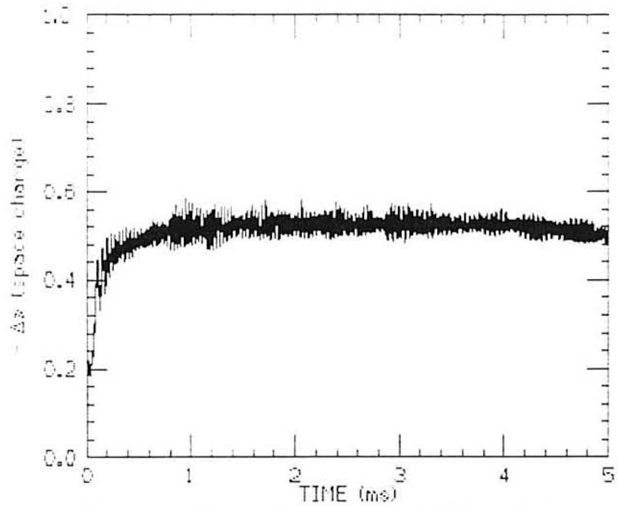

Figure 3: Space Charge tune Shift vs Time

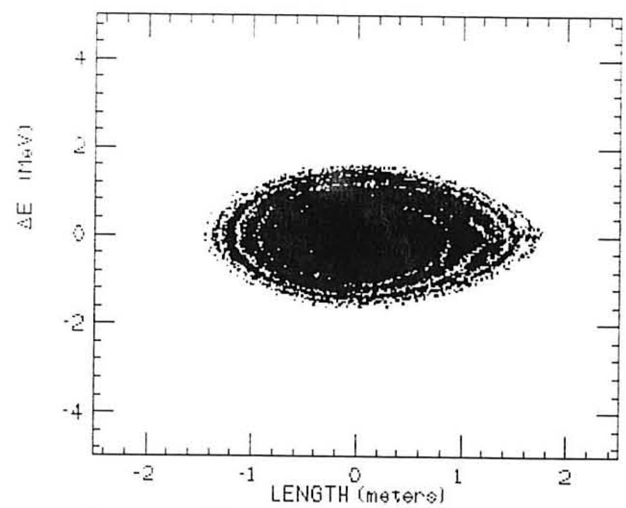

Figure 4: Phase space distribution at 1ms

sistatic evaluation as per the code ESME[8]. Due to the very small longitudinal emittance of the microbunches, for the first 1 ms, it was necessary to give nine kicks per turn for a proper estimate of the space charge forces. Beyond 1 ms a single kick per turn gave adequate results; we, however, present the results using nine kicks per turn. The transverse beam size corresponds to the average value of the beta-function. The actual beam pipe is not circular, but rather an ellipse: the effective beam pipe radius used was the geometric mean of the two axes of the ellipse. A particle is assumed to be lost if its average closed orbit deviation is more than 2 mm.

Figure 3 shows the space charge tune shift. The efficiency of capture, or transmission, is 98% for the entire cycle. The longitudinal space charge forces reduce the transverse tune shift by about 20%. The space charge effect, as seen from Figure 4, results in mixing of the particles and spreading the particles over most of the bucket area. The bunch area(95%) at 3 ms is about .030 eV s. The bunching factor at about 100 turns is comparable to the FNAL simulation[2,6].

6 Discussion

The rf voltage program, presented here, gives results comparable to the rf program at the FNAL[2,6] as far as transmission and bunching factors are concerned. Whether this will allow us to predict the behavior of the LEB using the FNAL booster as an experimental proof of transverse dynamics is not yet clear. There are several differences between the machines: for example superperiodicity, transition gamma and synchrotron tune. Another question is whether a simple scaling of the intensity and transverse emittance is theoretically sound. Though we can not give a rigorous proof, we expect that the rf program we propose, as far as adiabatic capture is concerned, is well optimized for good bunching factor and transmission.

Acknowledgement

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References

[1] S. Machida, *et., al.*, "Space Charge Effects in the SSC Low Energy Booster", *these Proceedings*.

[2] S. Stahl and C. Ankenbrandt, "Simulation of the Capture Process in the Fermilab Booster", *Proceedings 1987 IEEE Particle Accelerator Conference held at Washington, D.C. (16-19 March 1987)* p.1114.

[3] S. Stahl, *private communication*.

[4] R. K. Bhandari and S. Penner, "Beam Transfer Between the Coupled Cavity Linac and the Low Energy Synchrotron Booster for the SSC", *Proceedings of the 1990 Linear Accelerator Conference* p.411, September 1990.

[5] R. York, *et., al.*, "The Superconducting Supercollider Low Energy Booster: A Status Report", *these Proceedings*.

[6] N. K. Mahale and Miguel A. Furman, "Injection and Capture in the LEB", *SSCL-409, to be published in near future.*

[7] Miguel A. Furman, "RAMPRF: A Program for Synchronous Acceleration ", *these Proceedings*.

[8] J. A. MacLachlan, "Longitudinal Phasespace Tracking with Space Charge and Wall Coupling Impedance", *Fermilab FN-446 (February 1987)*.